Cross sections at 14 TeV and beyond

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John Campbell, Fermilab

Introduction

- Caveat: these slides mostly present results of calculations that I have performed for pp cross sections beyond 8 TeV.
  - emphasis on 14, 33 and 100 TeV.
- No deep insights, just some observations.
- Idea: test readiness of tools for investigating higher energies, look for interesting features and examine aspects of calculations that change in important ways at higher energies.
- Hope to instigate further discussion.

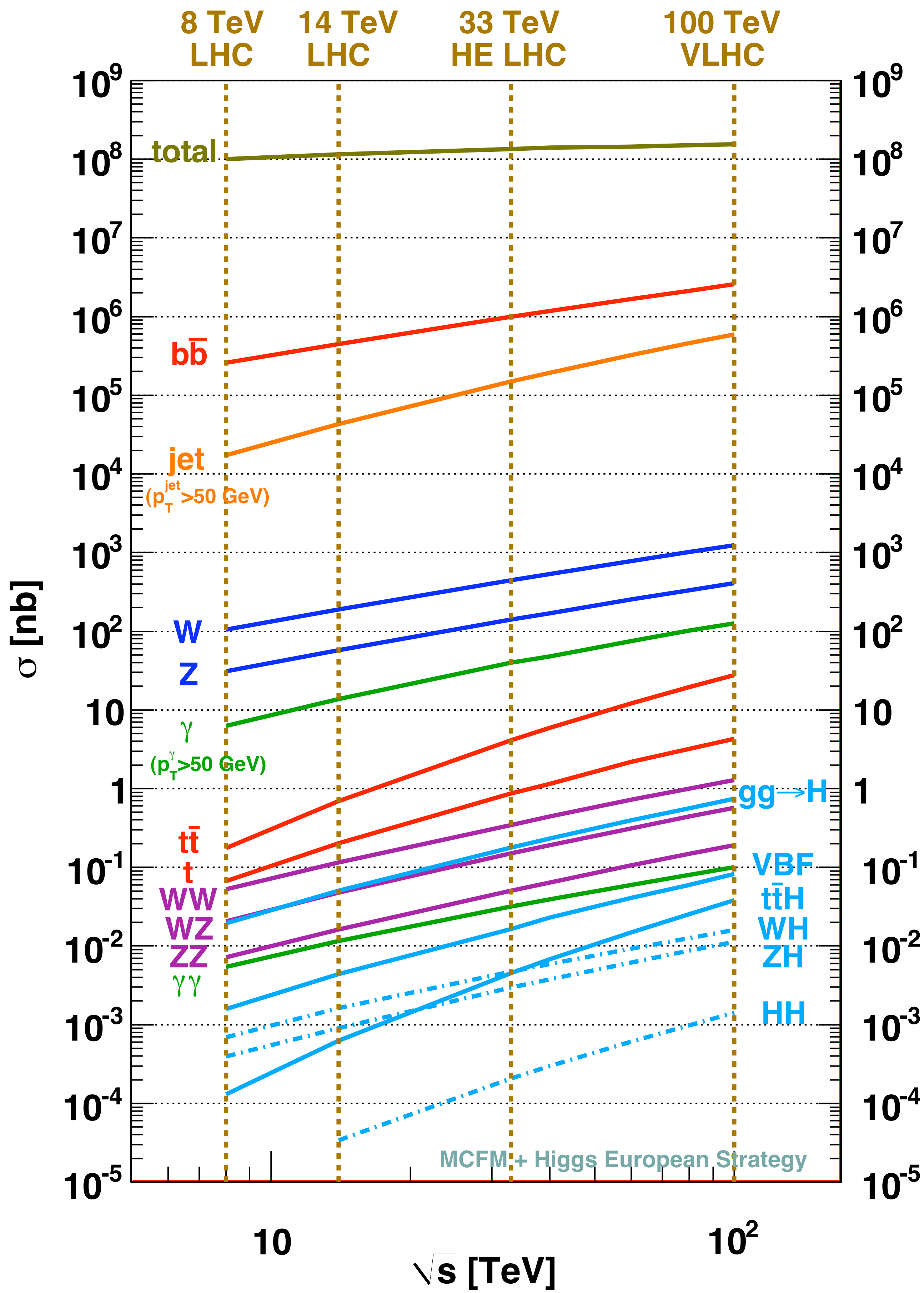
Overview

- Study using NLO results from MCFM and best Higgs predictions from European Strategy.
- Worth remembering double parton scattering cross section:

$$\sigma^{\mathrm{DPS}}_{XY} \sim \frac{\sigma_X\,\sigma_Y}{15\ \mathrm{mb}}$$

$$\Longrightarrow\quad \frac{\sigma^{\mathrm{DPS}}_{X(b\bar{b})}}{\sigma_X} = \frac{\sigma_{b\bar{b}}}{15\ \mathrm{mb}}$$

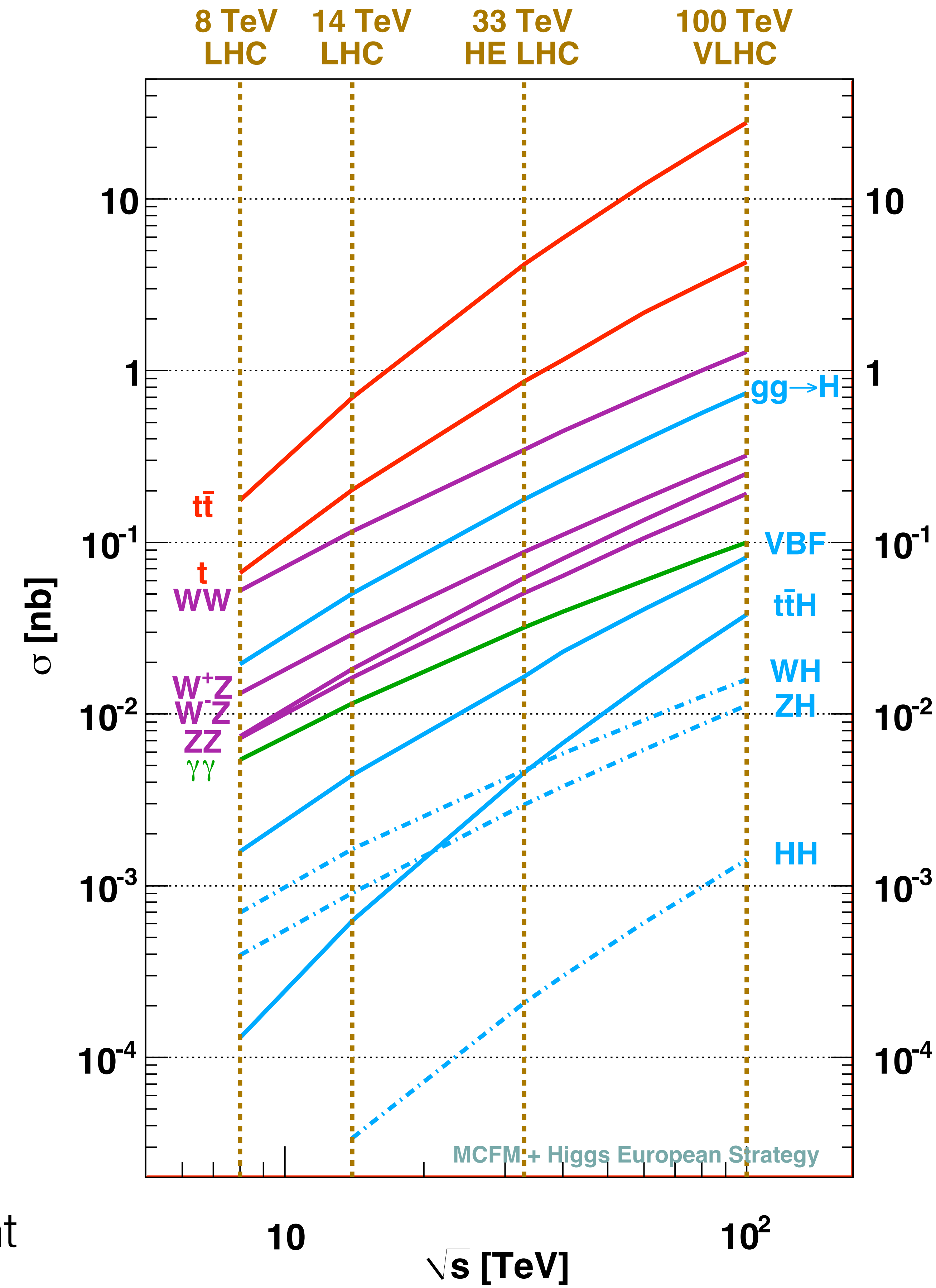
- Any cross section has approx. DPS bb contrib. of ~20% at 100 TeV (c.f. 2% at 8 TeV).



The business end

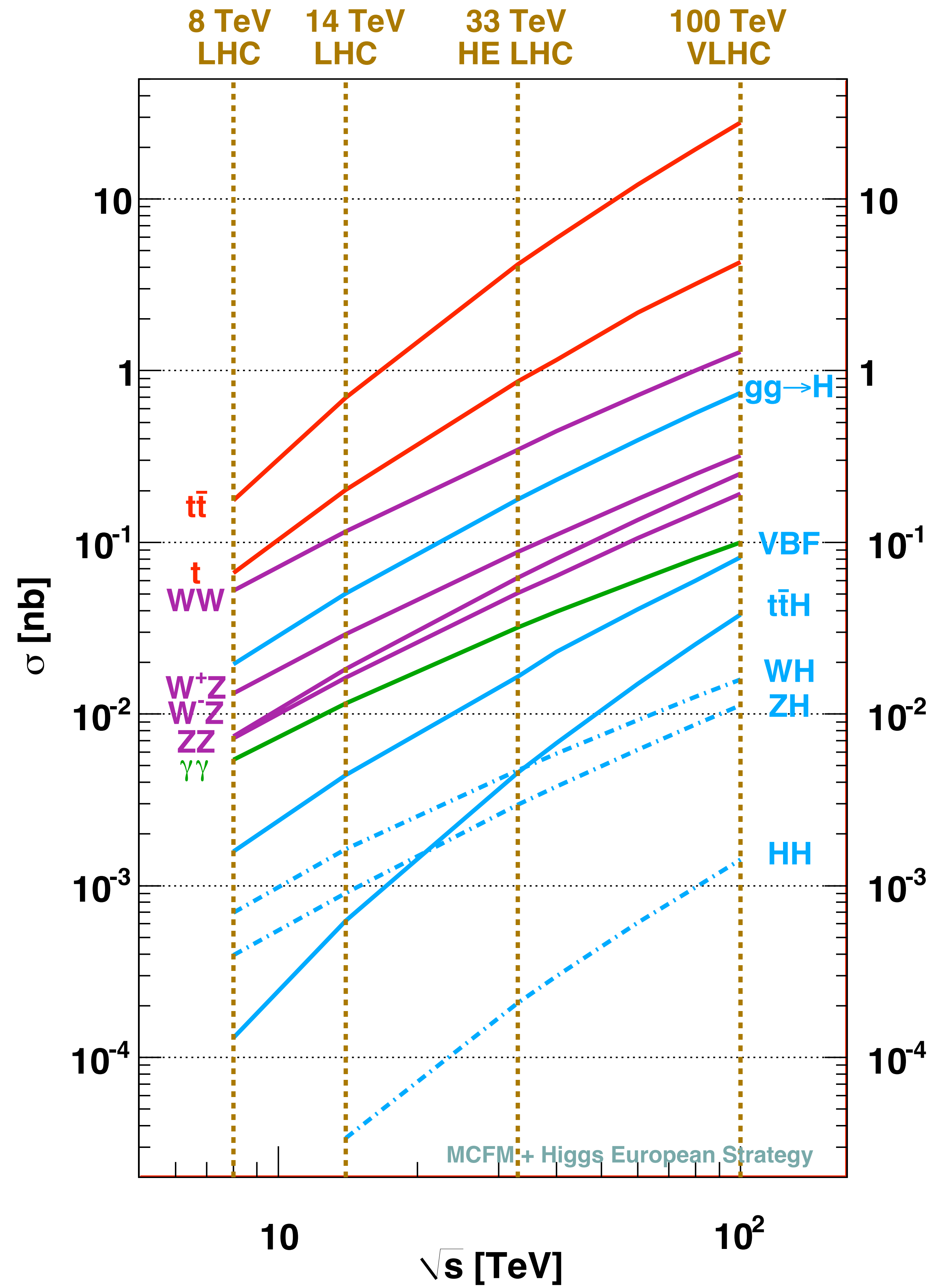
- Zoom in on most-important (small) cross sections.
- Top cross sections (pair and single) dominate even more at higher energies.
- After gg→H and VBF, Higgs production by ttH becomes next largest cross section at 33 TeV and beyond
    - grows like top pairs.
- Higgs pairs very challenging even at 100 TeV.

$$\frac{\sigma_{HH}}{\sigma_{t\bar{t}}} \sim 10^{-4}$$ (independent of energy)



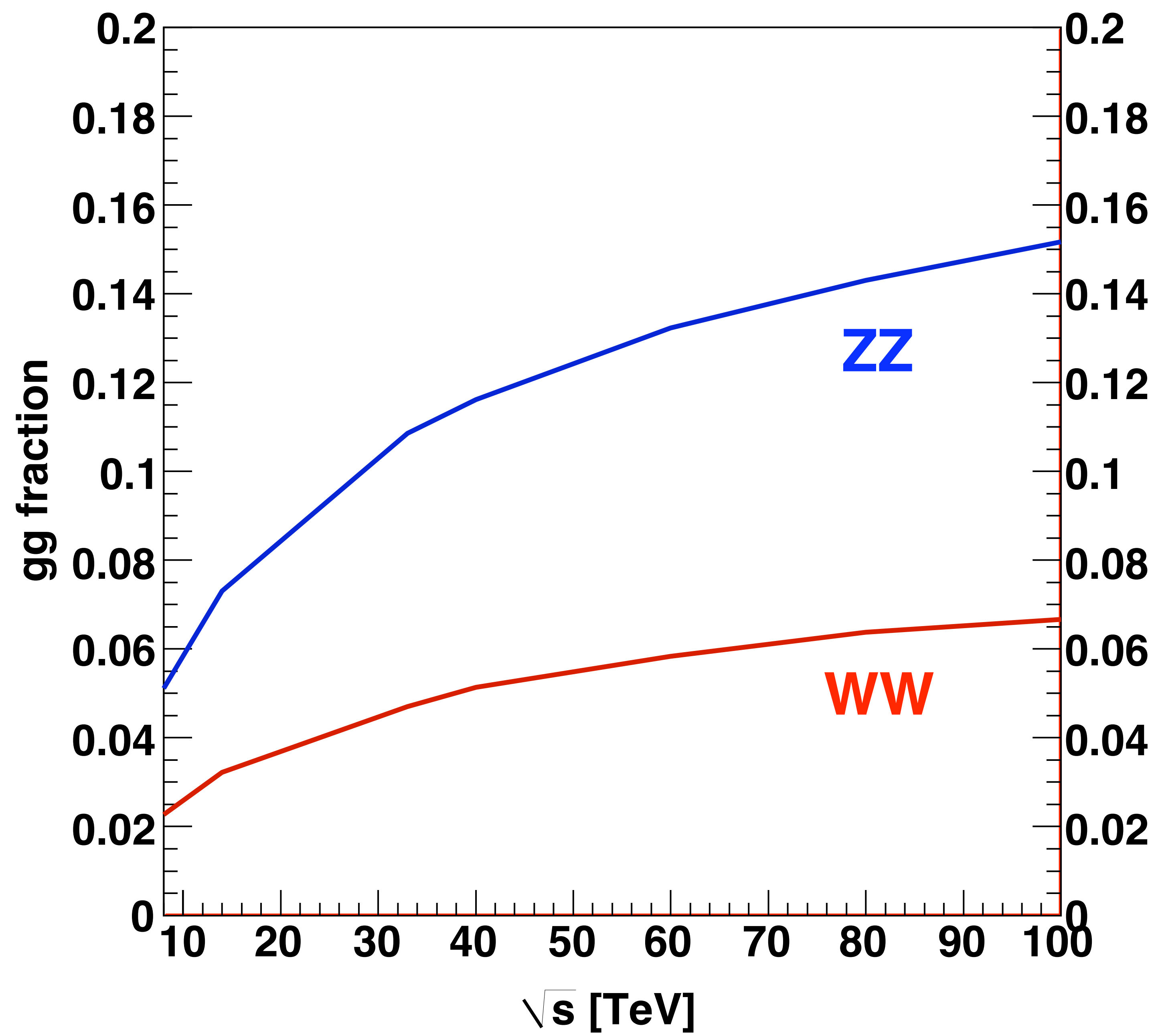
Comments

- Existing tools could give misleading results for some cross sections out of the box
  - e.g. mundane issues with numerical stability.
- Relative size of masses becoming small - $m_b^2/\hat{s},\ m_W^2/\hat{s}$; possible issues with evaluating virtual corrections.
- gg→WW a good example: amplitudes contain terms that explicitly diverge as $p_T(W)\to 0$; cuts for stability extended at 100 TeV.



Importance of gg contributions

- Contributions grow quite quickly for ZZ - very large for ostensibly NNLO effect.
- Underscores importance of computing these pieces to the next order (like a NLO calculation, since finite).
- Especially vital since more similar to Higgs production than the qq-initiated contributions.



K-factors as a function of √s

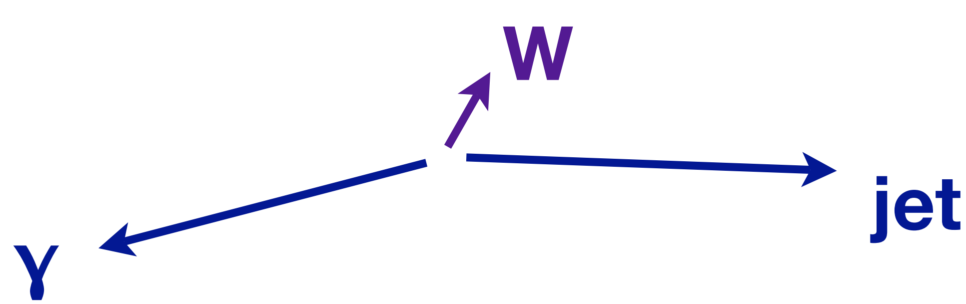
		14 TeV			33 TeV			100 TeV		
Process	μ_R^2, μ_F^2	σ_{LO} [pb]	σ_{NLO} [pb]	K-factor	σ_{LO} [pb]	σ_{NLO} [pb]	K-factor	σ_{LO} [pb]	σ_{NLO} [pb]	K-factor
W^+j ($p_T^W > 100$ GeV)	$M_W^2 + p_T^{W\,2}$	1040	1460	1.40	427	629	1.47	211	326	1.55
W^-j ($p_T^W > 100$ GeV)	$M_W^2 + p_T^{W\,2}$	679	984	1.45	291	443	1.52	152	238	1.57
Z^0j ($p_T^W > 100$ GeV)	$M_Z^2 + p_T^{Z\,2}$	681	962	1.41	312	460	1.41	164	254	1.55
γj ($p_T^\gamma > 50$ GeV)	$p_T^{\gamma\,2}$	8950	13780	1.54	2690	4030	1.47	1140	1666	1.46
$W^+\gamma$ ($p_T^\gamma > 50$ GeV)	$p_T^{\gamma\,2}$	4.40	13.9	3.16	1.90	10.0	5.26	0.889	9.29	10.4
$W^-\gamma$ ($p_T^\gamma > 50$ GeV)	$p_T^{\gamma\,2}$	2.79	10.0	3.58	1.29	7.50	5.81	0.668	7.20	10.8
$Z^0\gamma$ ($p_T^\gamma > 50$ GeV)	$p_T^{\gamma\,2}$	7.42	13.1	1.77	3.66	7.88	2.15	1.88	5.63	2.99
$\gamma\gamma$ (both $p_T^\gamma > 50$ GeV)	$m_{\gamma\gamma}^2$	8.59	11.5	1.34	2.70	3.65	1.35	1.17	1.57	1.34
$\ell^+\ell^-$ ($m_{\ell^+\ell^-} > 150$ GeV)	$m_{\ell^+\ell^-}^2$	7.27	8.72	1.20	20.9	23.6	1.13	73.7	77.0	1.04

cuts at 14 TeV

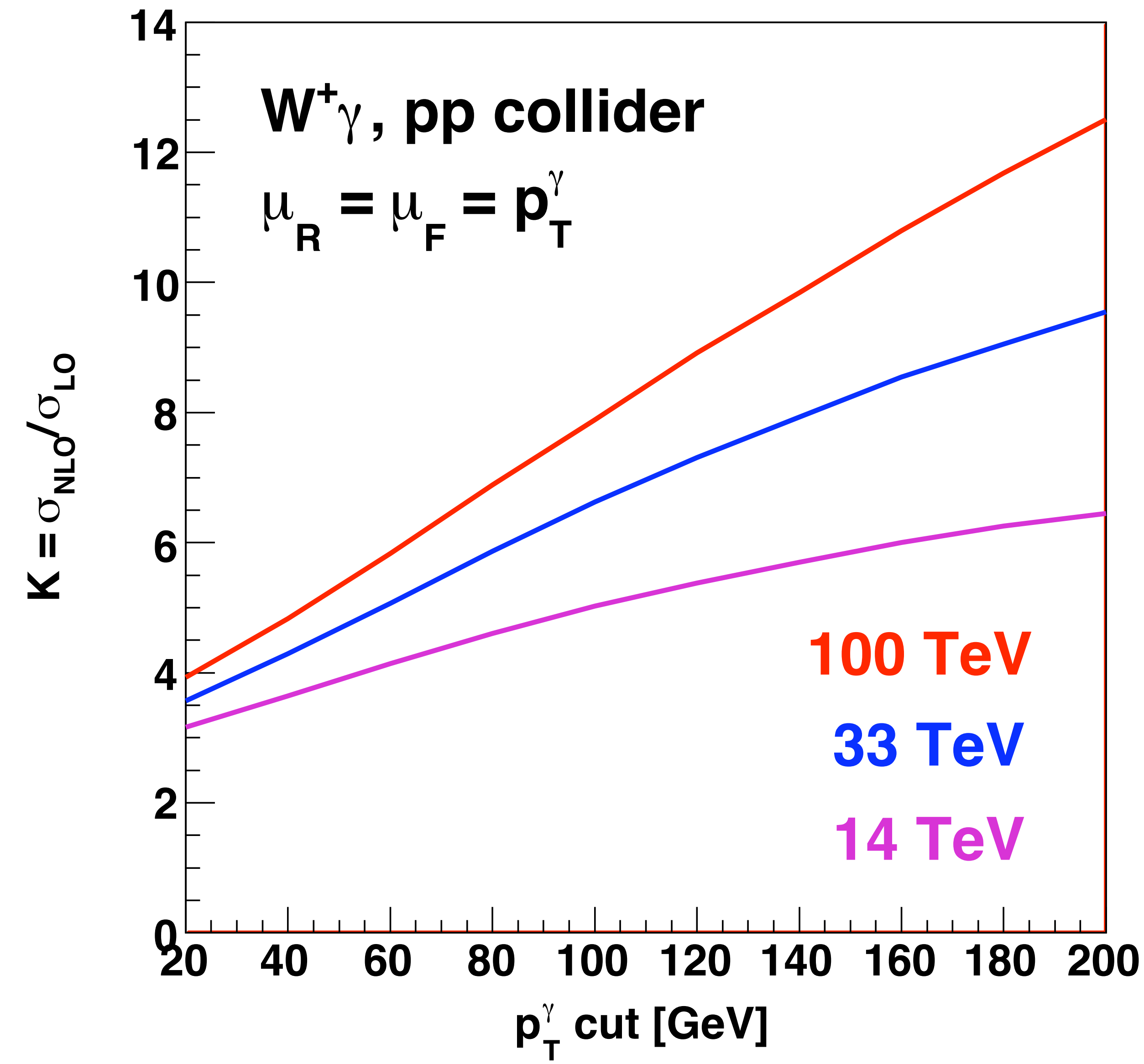
- Part of studies for BSM backgrounds (J. Wacker et al); cuts on basic objects double from 14 to 33 TeV, again from 33 to 100 TeV.
- Smooth dependence of K-factor on energy, no strange behaviour.
- Except for W/Z+photon cases, where K-factors grow rapidly with energy. However, NLO predictions close to cross sections found using matched Madgraph samples.

Wγ in more detail

- Reasons for large corrections understood:
  - lifting of radiation zero that is present at LO only
  - enhancement by gluonic channels entering at NLO
  - dominance of new kinematic configurations that enter in the real corrections:



(produce high-p_T photon by recoil against jet)



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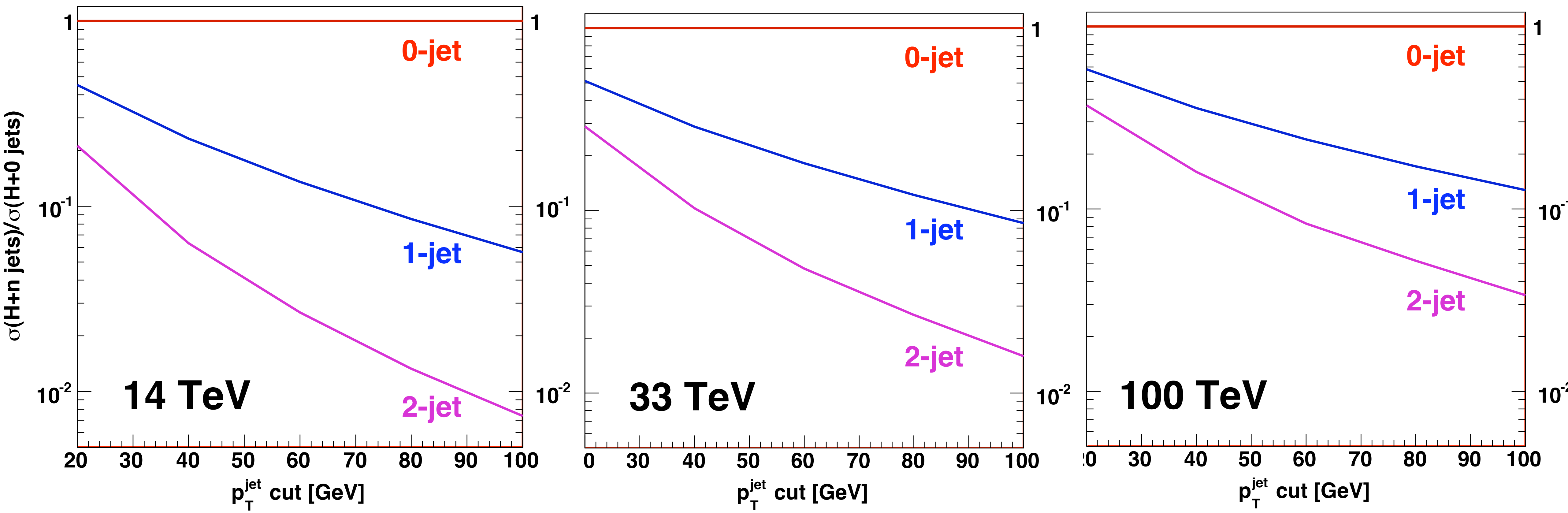
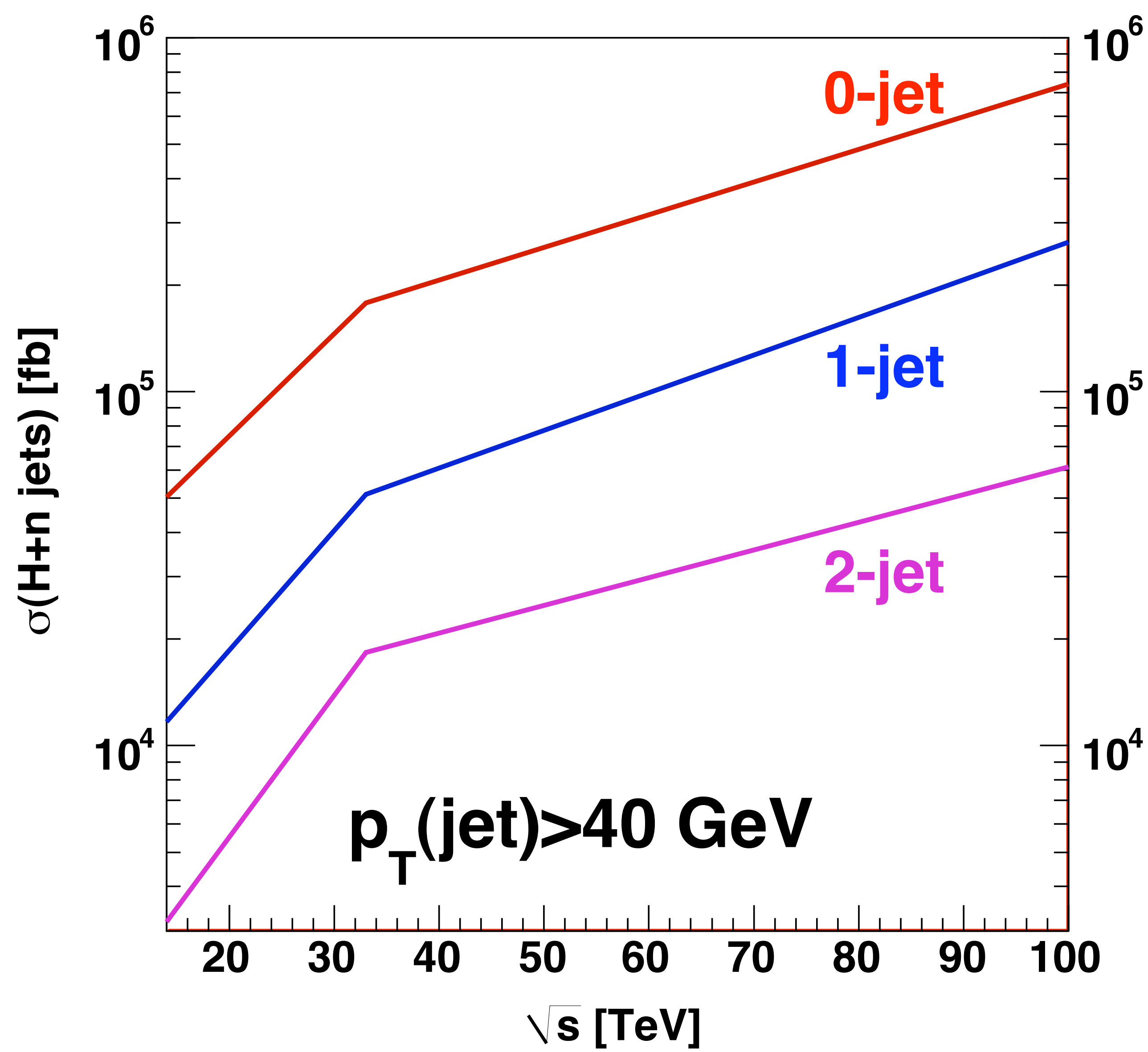
Must at least be aware of the issue in order to ensure sensible results for projections at higher energies

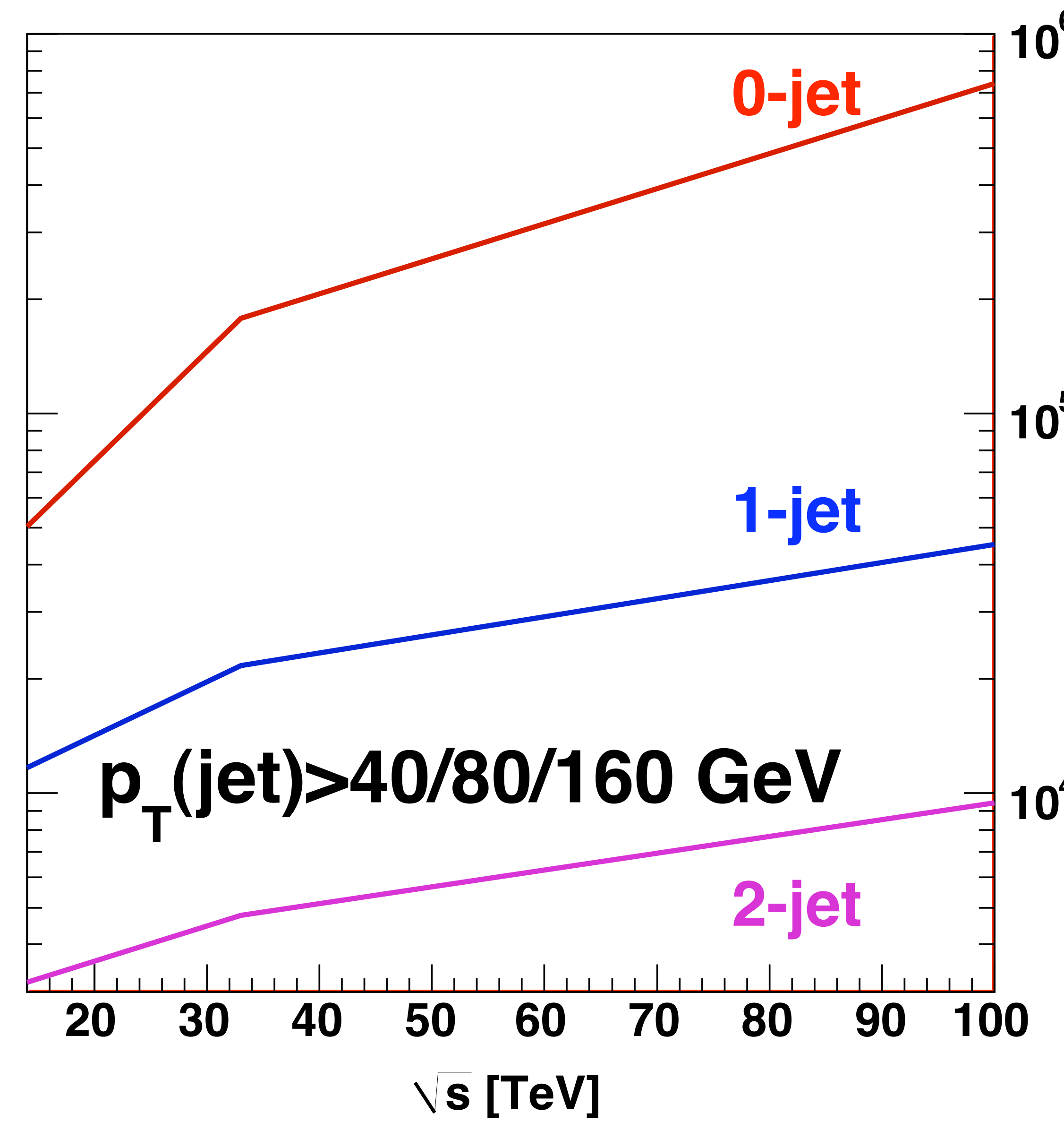
Higgs+jet cross sections



- ✦ 0-jet cross sections at NNLO; 1- and 2-jet at NLO.
- ✦ More jets at higher energies means vetoing jets has a more severe effect and leads to larger uncertainties.
- ✦ Presence of more jets means it is even more important to use matched samples with sufficiently high jet multiplicity.

Higgs+jets vs. $\sqrt{s}$





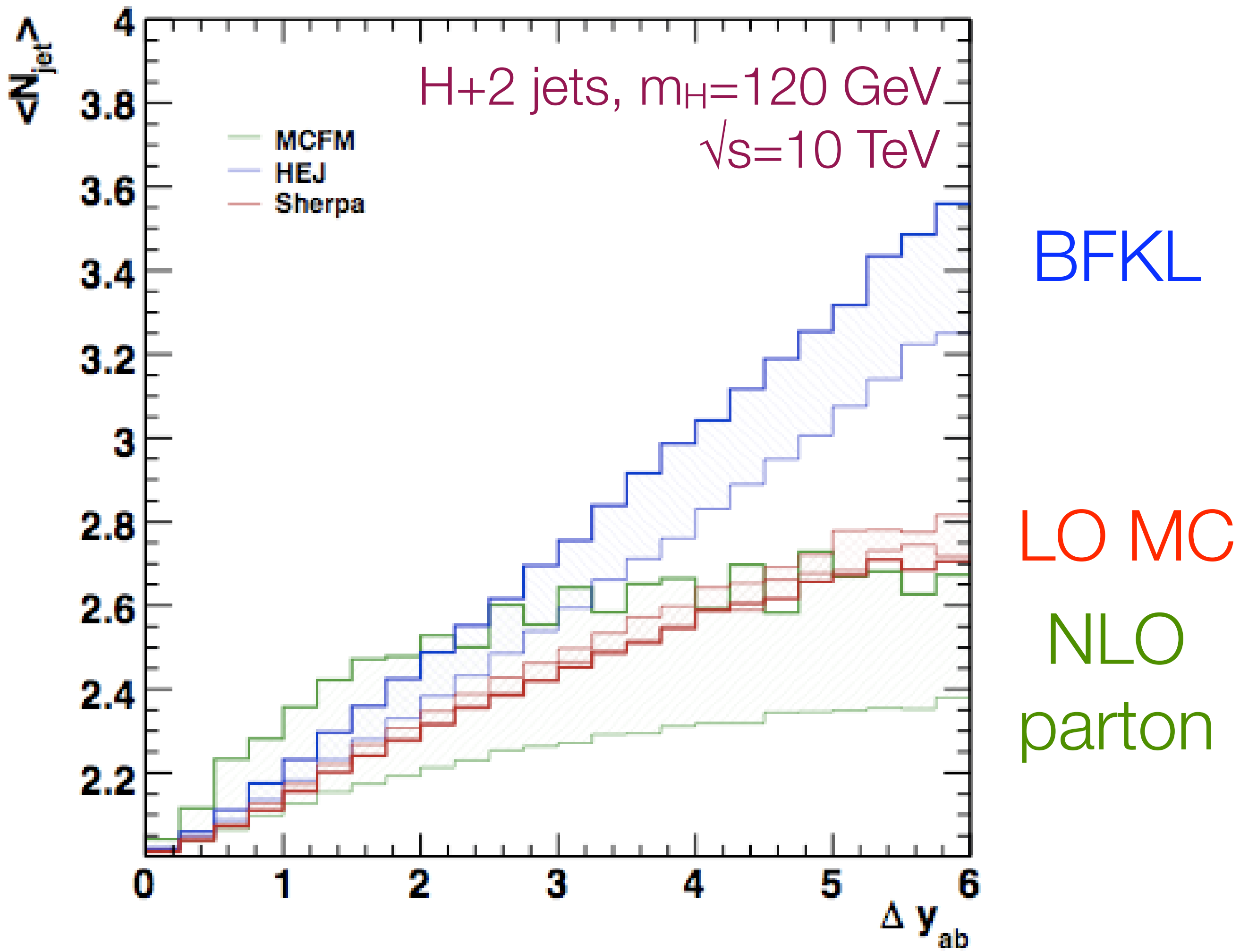
constant jet cut

approx. scaling with $\sqrt{s}$

→ actually multi-jet fractions less at higher energies

Exploring QCD dynamics

- Look for differences between usual QCD tools and one based on BFKL-type small-x resummation (HEJ).
- Need a probe that looks at large rapidities: expect differences at large rapidity separation between jets in X+jet events (X=W,Z,H).



Les Houches 2009

Need to repeat study at higher energies and with updated tools.

In particular, need to take advantage of modern (NLO) matched samples.

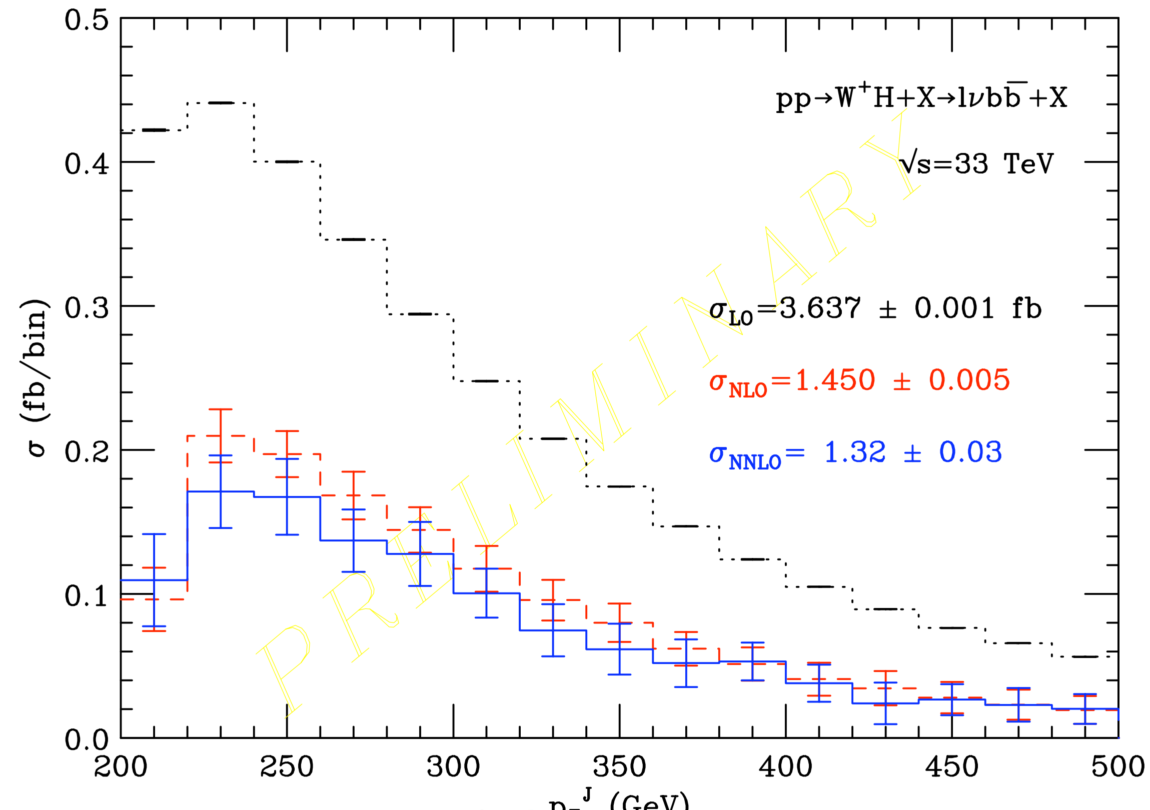
Summary of ongoing work/to-do

- Collect predictions for H+2 jet study to estimate sensitivity to BFKL logarithms.

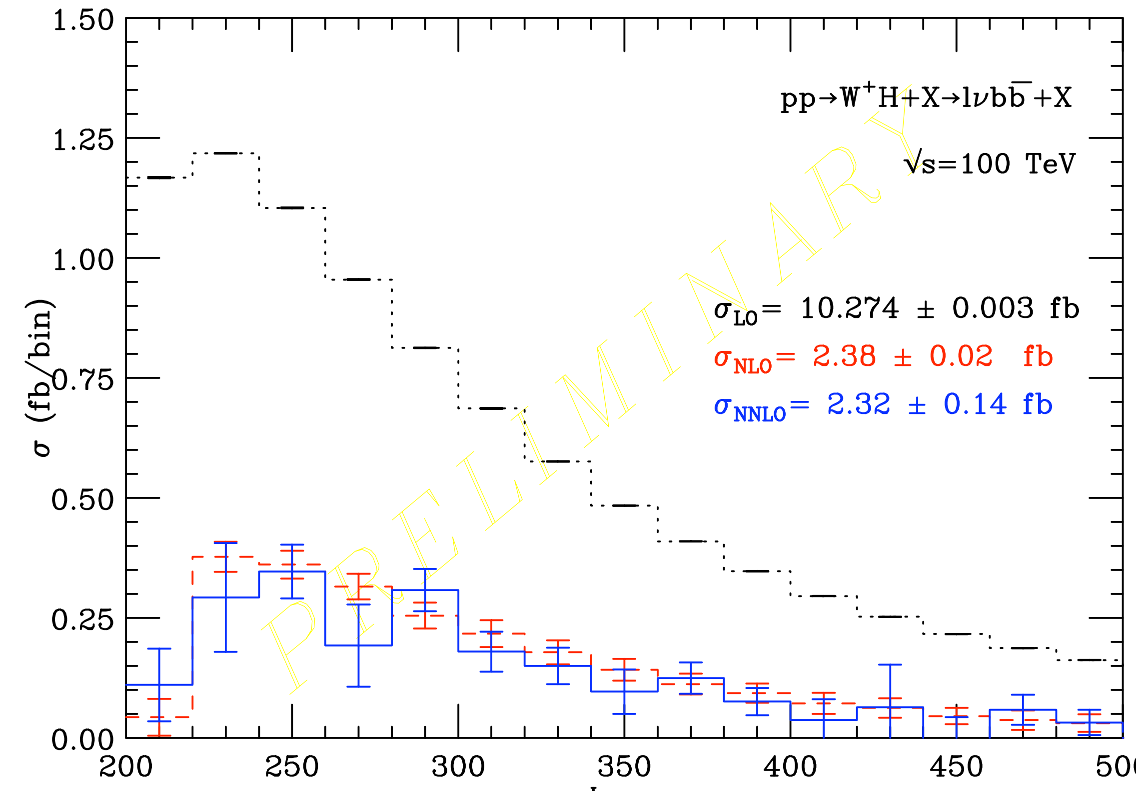
- Assess interest in collating best possible cross-sections and uncertainties (pdf+α_s variation)
  - some of this work already done in-house (CMS, ATLAS?) and information also available elsewhere.

- Put together other studies in pQCD that have also been performed at higher energies.

Other studies beyond 14 TeV

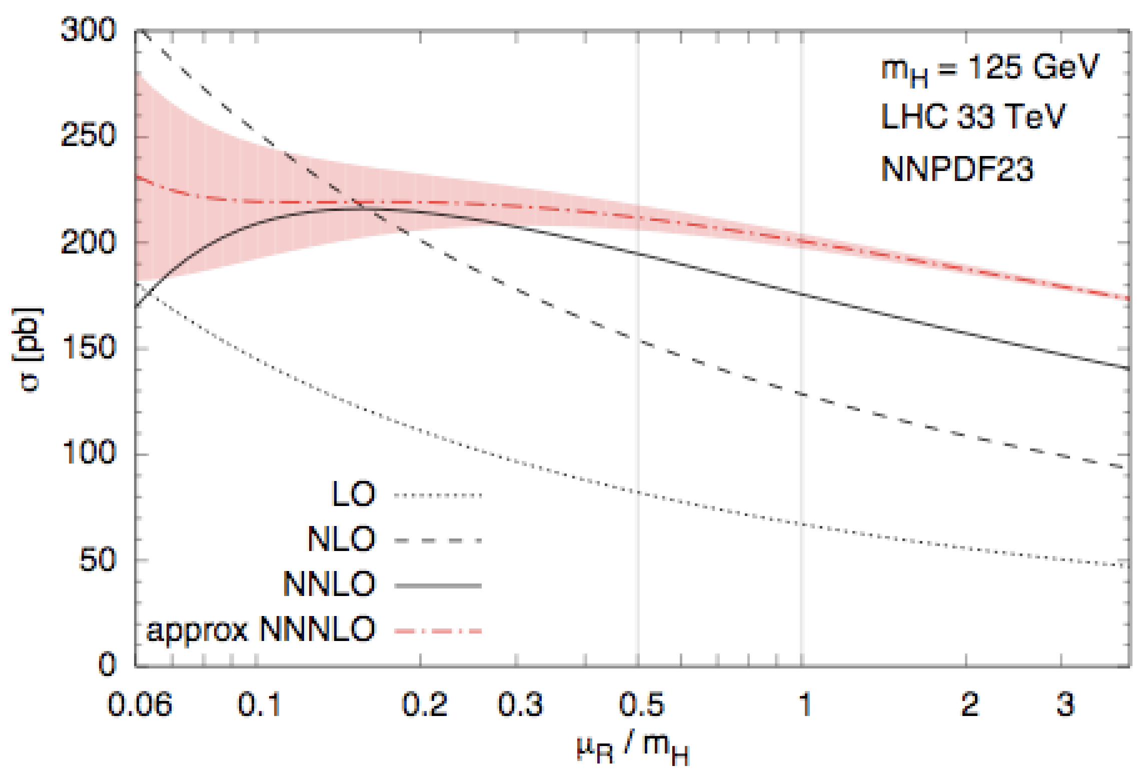


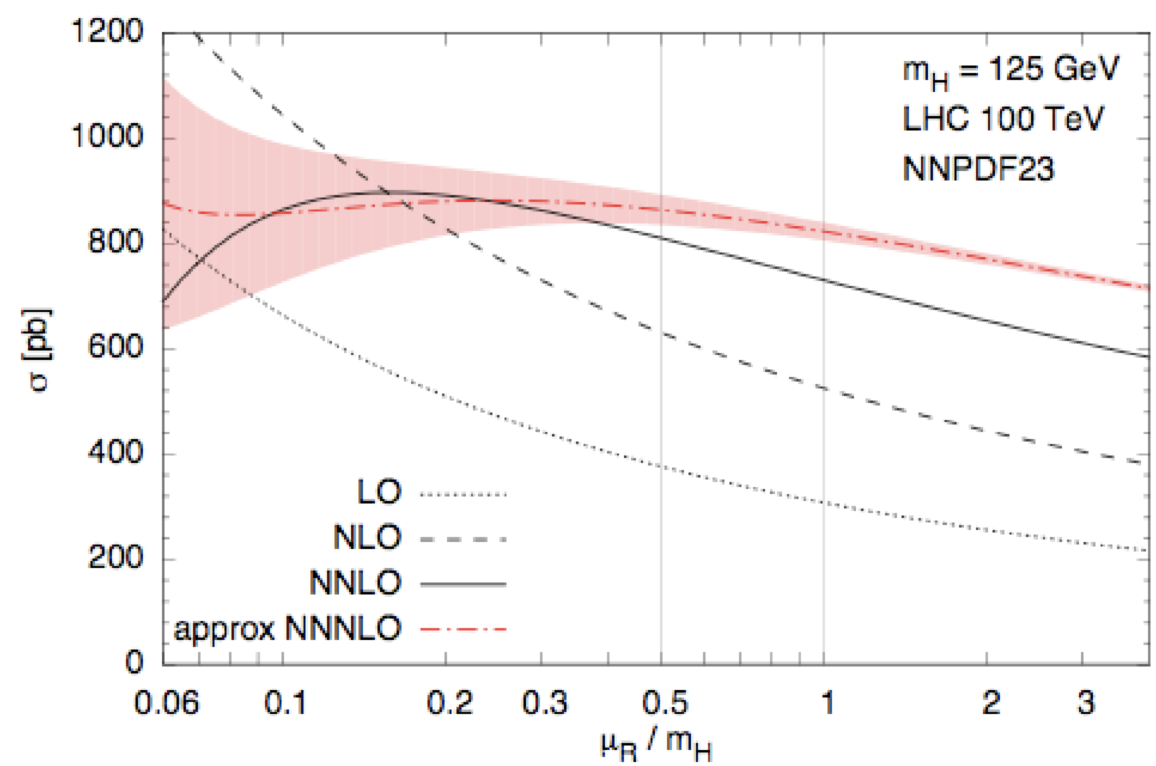
Higgs hadron-level cross section



Higgs hadron-level cross section

boosted WH





approx. N^3LO gg→H

Discussion